THE CONDITIONS OF TEMPERATURE AND HUMIDITY OF THE AIR BETWEEN THE SKIN AND SHIRT OF MAN.

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(With 2 Figures in the text.)

Introduction.

Previous workers who have investigated the conditions of temperature and humidity beneath the shirt, have done so mainly in relation to the hygiene of clothing. Towards the end of the last century, Rubner and his colleagues did some work bearing on this problem. In the course of investigations connected with clothing, the temperature and humidity of the air beneath it were measured. Rubner and von Lewaschew (1896) made use of a small composite thermometer and hair hygrometer, which had been designed by Lambrecht. This apparatus needed frequent recalibrations, and was satisfactory only within narrow limits, so that I think the results obtained must be regarded with caution. They found that the relative humidity of the air beneath the shirt was often as low as 25 per cent., and that its temperature rose as the external temperature became higher, or the external air moister. They found the temperature to be higher than either Leonard Hill or I have found under similar conditions, probably because the thermometer was enclosed in the apparatus and protected from cooling.

The nature of the clothing has a great influence on the loss of heat and moisture from the skin. Kratschmer (1896) gives tables showing the amount of moisture taken up by various fabrics, but it appears that we know nothing of the effects of materials on the humidity conditions of the air enclosed.

This subject has been touched on by Leonard Hill (1914) whilst dealing with problems of industrial hygiene. He used a wet and dry-bulb thermometer to investigate the conditions under the shirt. The main objection to this method is that unless the wet bulb is in a current of air (which it was not), the reading is inaccurate, and will show too high a relative humidity. Also, the wet bulb will give off moisture into the enclosed space and raise its humidity. His results show considerably higher humidities than Rubner or I found under similar conditions, but the dry-bulb temperatures are in agreement with my results.

The air under the shirt appears to have a slightly higher CO_2 content than the air outside. Kratschmer (1896) showed that when the outside air has about 0·04 per cent. carbon dioxide, the air under the shirt has about 0·08 per

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cent. This figure is imperceptible to man, and I have not dealt at all with this side of the question.

I have studied the temperature and humidity conditions of the air beneath the shirt for reasons different from those of the investigators mentioned above. Lice live in this environment, and changes in its "microclimate" no doubt affect them. They are seasonal insects, and particularly so in hot climates, so that if we understood how external conditions altered the conditions below the shirt, we should understand more exactly how these changes in the external climate affected the lice. Figures of this kind might also be of value to workers on heat stroke.

METHODS.

Using a different type of apparatus from the previous workers, I have attempted to carry this work a step further. The observations were all performed on myself, and I always wore the same or similar clothes. The observations were made when I was at rest, and in still air. I sat in various chambers, at various temperatures and humidities, and measured the conditions when an equilibrium had been set up—this happened in about half an hour, and so one hour was always allowed to elapse before the final reading was taken.

An accurate mercury thermometer was used to measure the temperatures. The skin temperature was taken by pressing the bulb against the skin, under the arm. The temperature of the air enclosed by the shirt was obtained by placing the bulb of the thermometer in the air space beneath the arm, and not allowing it to touch the skin. With this method of measurement, results taken under identical conditions appeared to vary less than half a degree.

The humidity of the air beneath the shirt was measured with a Rideal and Hannah (1915) chemical hygrometer, in which I made a number of modifications. A description of this apparatus and its working has been recently given by Buxton (1931 *b*). The principle of the apparatus is that a sample of air is taken and measured accurately at atmospheric pressure. The air is then dried by being passed several times over strong sulphuric acid, and on re-measuring at atmospheric pressure any decrease in volume shows how much water vapour was originally present. The chemical hygrometer measures directly the pressure of water vapour present in the air. When the temperature is known the vapour pressure can be easily converted into terms of relative humidity or saturation deficiency. The apparatus is filled with mercury, which is moved in the apparatus by raising and lowering reservoirs. To take a sample of air from under the clothes, a length of glass capillary tubing is fixed on to the inlet of the hygrometer. By raising the reservoir, mercury can be made to fill this capillary tube; the tube filled with mercury is put up the sleeve, and a sample of 10 c.c. of air removed from below the armpit. The sample is almost certainly a true one of the air beneath the clothes, partly because the capillary tube was filled with mercury so that there was no dead-space air in the apparatus; partly because the small sample of air taken—10 c.c.—would not be so great that an appreciable amount would have been drawn straight in through the clothes from outside. Moreover, putting a capillary tube up the sleeve will not upset the natural conditions below the clothes as much as would the methods of the previous workers. The samples of air were taken, for every observation, from as nearly as possible the same position, but the movements of the chest wall must keep the air under the shirt fairly well mixed, and there should be no appreciable error if the samples were not taken from exactly the same spot every time.

Results.

The results obtained are shown in the accompanying table (p. 271). The external conditions varied very widely. The lowest temperature was 0° C., and the highest 41° C. The relative humidity varied between 38 and 90 per cent., and the absolute humidity between 3·2 and 27 mm. Under the shirt the temperature varied between 23 and 37° C., and the relative humidity between 23 and 70 per cent. The absolute humidity varied between 4·9 and 30 mm.

Fig. 1 shows the same results graphically. The black spots record the external conditions, and are connected by lines to crosses which show the temperature and relative humidity under the shirt when the experimenter was exposed to those conditions. The numbers on the lines connecting the circles and crosses on the graphs correspond to the numbers in the table. The same results are shown in Fig. 2, but here temperature is plotted against saturation deficiency. The symbols are the same as in Fig. 1. It will be seen that, whereas the relative humidity of the air beneath the shirt varies so widely, the saturation deficiency, in my experiments, varies only between 13 and 18 mm.

The reason for plotting the results as in Fig. 2 is that I am interested in the conditions as they apply to insects, especially *Pediculus humanus corporis*. We have reason to believe that the loss of water by insects is proportional to the saturation deficiency of the air (Buxton, 1931 *a*) at different temperatures. This has not yet been definitely proved, but certainly the rate of loss of water is much more nearly proportional to the saturation deficiency of the air than it is to the relative humidity.

Discussion.

When the external air is cooler than body temperature, the body warms up the air under the shirt. In cold air, at 0° C., the air is warmed up to 23° C. Now saturated air at 0° C. contains 4·6 mm. of water vapour, while at 23° C. it would contain 21·1 mm. if it were saturated. Thus, if the air outside is cold, and the body warms some of this air up under the shirt but does not add much moisture to it, then the air under the shirt will have a low relative humidity. Actually, as shown in the table, when the external air temperature was 0° C., the body increased the absolute humidity of the air under the shirt from

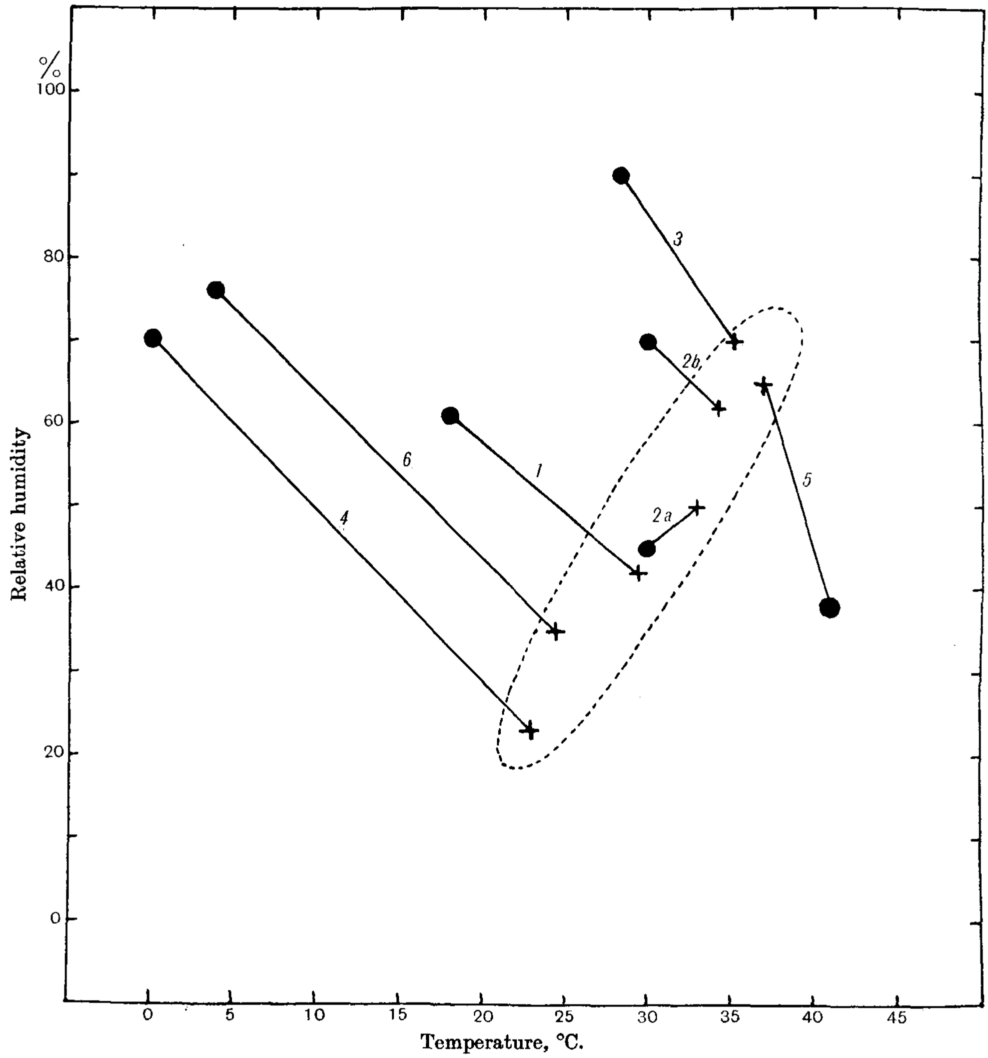

Fig. 1. For description see text. The dotted line encloses the area representing the range of readings under the shirt.

Table of Results.

	Details of external conditions				Skin temperature of chest (clothed)	Details of conditions under the shirt			
	Temperature ° C.	Absolute humidity mm.	Relative humidity %	Saturation deficiency mm.	° C.	Temperature ° C.	Absolute humidity mm.	Relative humidity %	Saturation deficiency mm.
In laboratory	18	9·5	61	6	35·5	29·4–29·8	12·5–13	42	17
. In "30° C." room	30	13	45	19	36·1	32·5–33	18	50	18
. In "30° C." room, hung with wet towels	30	22	70	10	36·7	34·2	25·2	62	17
In air-conditioning room	28·4	27	90	3	37·3	35·2	29	70	13
In refrigerating chamber	0	3·2	70	1·5	32·5–33	23	4·9	23	16
In air-conditioning room	41	20·5	38	37	36·9	37	30	65	16·7
On roof. Very slight snow falling	3·8	4·6	76	1·4	31	24·5	8·1	35	15

3·2 mm. to 4·9 mm., but as it also raised the temperature to 23° C., the relative humidity beneath the shirt was only 23 per cent., and its saturation deficiency was 16 mm.

The two results obtained with an outside temperature of 30° C. are interesting. In the first the relative humidity of the external air was 45 per cent., and its absolute humidity 13 mm. Under the shirt the air reached a

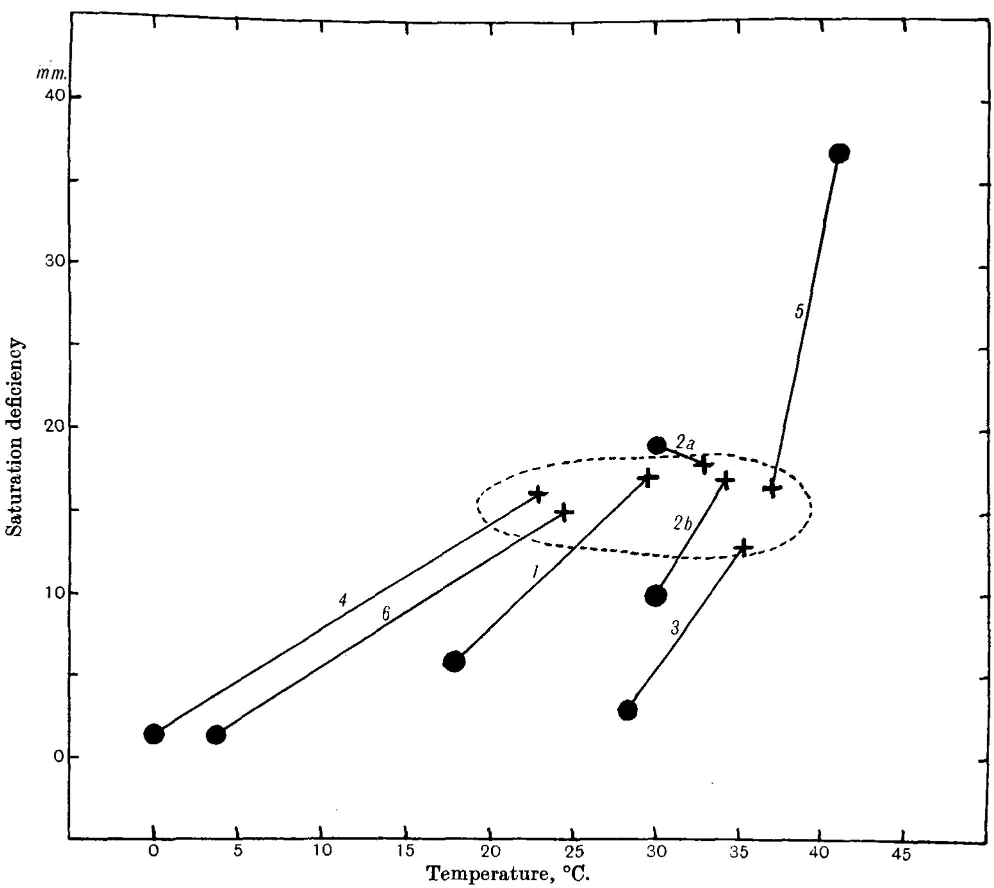

Fig. 2. For description see text.

temperature of 32·5° C., and the moisture given off by the body increased the absolute humidity to 18 mm.; but because of the increase in temperature the relative humidity of the air beneath the shirt only rose to 50 per cent. On the second occasion, with an external temperature of 30° C., and a relative humidity of 70 per cent., the air under the shirt reached a temperature of 34·5° C., the absolute humidity was raised from 22 to 25·5 mm., and the relative humidity was 62 per cent. Because the temperature beneath the shirt was raised so much, the saturation deficiency was 17 mm.—only 1 mm. lower than when the external temperature was the same but the air much less moist.

The reason why the saturation deficiency of the air under the shirt was found to be so nearly constant (Fig. 2) in spite of such different external conditions is not at all mysterious. When the external air becomes warmer, the air under the shirt becomes warmer also. But in warm moist air the skin cannot keep cool so efficiently as in dry air, and the temperature beneath the shirt rises more than it does in dry air; the amount of water vapour there also increases. This means that the greater the amount of water vapour beneath the shirt the higher the temperature of the air, and as warm air can hold more water vapour than cool the saturation deficiency tends to remain constant.

I did not work under one set of conditions—where the air is moist and warmer than the body. It is difficult to reproduce these conditions in the laboratory, and long exposure to them is dangerous. In very hot moist air the air beneath the clothes would presumably become saturated, and its saturation deficiency would be zero. When I sat in air at 28·4° C. and 90 per cent. relative humidity, I found that the air beneath my shirt had a relative humidity of 70 per cent. and the lowest saturation deficiency which I found in my experiments (13 mm.).

The results described were obtained under certain defined circumstances. They were obtained when I was at rest, and after the air beneath my clothes had reached equilibrium with the outside air. They do not necessarily apply to anyone else, or to myself when wearing other clothes, or when taking exercise. The clothing worn must have a considerable influence on the air it encloses, but it may be noted that, in the laboratory, the humidity of the air from under the clothes of three different people at rest was almost the same.

SUMMARY.

Methods for measuring the temperature and humidity of the air beneath the shirt are described.

Conditions of temperature and humidity under the shirt are described, for a resting person, with external temperatures varying between 0° C. and 41° C., under different atmospheric humidities. The air beneath the shirt varied between 23° C. and 37° C., and 23 and 70 per cent. relative humidity. The saturation deficiency of the air beneath the shirt varied very little—only between 13 and 18 mm.—in all the observations taken.

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